DETERMINATION OF THE BASIS FOR TEMPERATURE COMPENSATION IN ETC IGNITED SOLID PROPELLANT GUNS

R. A. Pesce-Rodriguez and R. A. Beyer
Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5069

ABSTRACT

A series of experiments and reanalysis of previously published results has led to the discovery of the key interaction between the plasma of an electrothermal igniter and the gun propellant in large caliber cannon. It has been shown that the intense visible and near infrared light from the plasma discharge create a greatly enhanced surface area for a limited fraction of the propelling charge. This extra surface area, promptly ignited by the plasma, causes the rapid pressurization of the gun breech. The remainder of the charge is unaffected by the plasma radiation and burns according to usual interior ballistics design. This provides a mechanism for compensation for the lower burning rates of cold propellants, which would otherwise result in decreased performance.

1. INTRODUCTION

A series of experiments has been combined with analysis of previously reported observations to develop an understanding of the key mechanisms of high-energy electrical discharge plasma ignition of gun propellants as used in electrothermal chemical (ETC) and electrothermal ignited (ETI) large-caliber guns. It has been shown that enhanced surface area due to interaction of some classes of propellant with the intense visible and near-infrared light from the plasma is the key to the enhanced performance of plasma-ignited cannons. In particular, an explanation of the significant reduction in the variation in performance of a gun due to the temperature of the propelling charge when ignited with plasma will provide the knowledge base for significant reduction in the weight, volume, and power requirements of future ignition systems.

2. EXPERIMENTAL

The key experiments were conducted in an experimental fixture that unambiguously separated the highly intense radiation of the plasma from the high velocity flows, highly reactive ions and atoms, and hot particles that are also characteristic of these plasmas. A schematic of the functional part of the device is shown in Figure 1. The electrodes shown are connected to a conventional PFN pulsed power source to drive the plasma discharge between them. The energy and power values of the discharge are measured and allow full characterization of the key plasma properties. These observations have used up to 50 kJ of stored energy in the PFN, an amount sufficient to ignite large caliber cannon. The polycarbonate tube serves two functions: (1) it confines the discharge, thereby increasing pressure and the intensity of the radiation and (2) it protects the propellant sample from direct contact with the non-radiative elements of the plasma. Polycarbonate has broad transmission across the visible and near infrared and limited transmission in the infrared. Initiation of the discharge is by a 0.13-mm diameter nickel fuse wire.

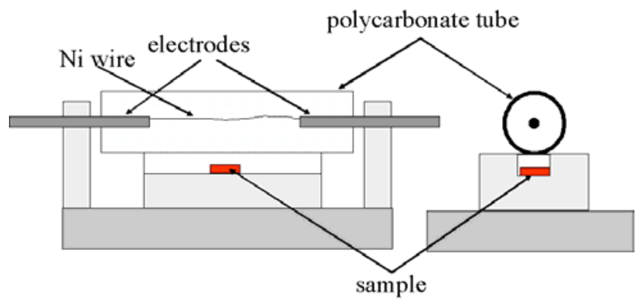

Figure 1: Schematic of Device for Studying Effect of Plasma Radiation on Propellant

The primary propellant used in these studies was graphite-free JA2 sheet (GF-JA2). This choice was made because of the indications from gun firings that showed favorable response by JA2 propellant charges compared to other standard propellants such as M30. By removing the graphite, the propellant response to light is stretched through more of the propellant volume to enable more complete diagnostics. The rectangular propellant samples were mounted about 2 mm outside (but not touching) the polycarbonate tube as shown in Figure 1. Other standard and experimental propellants were also studied in limited quantities.

3. RESULTS

The physical change in GF-JA2 is shown in Figure 2 for a low level of power in the discharge. The features that look like bubbles under the surface are actually one-dimensional, and appear flat viewed from edge on. This part of the structure is thought to be related to the extrusion and rolling process used to form the sheet propellant. It was observed that the number of

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **00 DEC 2004**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Determination Of The Basis For Temperature Compensation In Etc Ignited Solid Propellant Guns**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Research Laboratory Aberdeen Proving Ground, MD 21005-5069**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001736, Proceedings for the Army Science Conference (24th) Held on 29 November - 2 December 2005 in Orlando, Florida. , The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**2**	

"bubbles" increases and their size decreases as the intensity of the light increases.

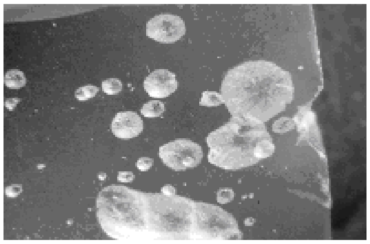

Figure 2: GF-JA2 following exposure to low power plasma discharges.

The damage done to the propellant was quantified by weighing the samples to determine the mass loss during exposure. A good correlation between mass loss and peak power of the discharge was found. The radiation from the plasma is also known to correlate well with power. A poor correlation was observed between mass loss and total energy of the discharge, which was previously erroneously used by many researchers as a standard control parameter. This apparent correlation had occurred because of the use in many experiments of fixed pulse length where changes in energy were also changes in peak power.

Decomposition gases were captured for chemical analysis by irradiating the propellant samples (graphite-free and standard JA2) while inside gas-tight syringes and then injected into a gas sample cell of a Fourier Transform Infrared (FTIR) spectrometer for analysis. The key observation from these absorption spectra is that while the magnitude of the response is quite different depending on whether the propellant contains graphite, the gas composition produced is the same for JA2 with and without graphite. In both cases there is abundant CO and CO_2 and CH_4 but no detectable oxides of nitrogen. This result indicates that the graphite in standard JA2 does not change the nature of reaction from the plasma radiation but merely serves to shield the inner portion of the sample from the light energy. This observation validates our use of GF-JA2 to understand the response of standard JA2 to plasma.

It was a general observation that transparent propellants, such as M9 or graphite-free JA2, absorb plasma radiation and form surface blisters and in-depth voids resulting in increased surface area and porosity, which increases susceptibility to reaction with plasma components (i.e. ions, radicals, metal particles from exploded wire). Experiments with M9 have shown that gasification within radiation-induced voids can be sufficient to blow a grain into pieces. Calculations of expected pressure rise based on mass loss for plasma-exposed M30 and standard JA2 in a small-scale fixture indicated that the observed pressure for JA2 is significantly less than predicted, presumably as a result of ablation of relatively large bits of propellant that fail to completely decompose during the experiment. Further work indicated that that decomposition gases generated by radiation–exposed propellant does not contribute to post-plasma decomposition, suggesting that the material is so porous that the gases can easily escape and not contribute to autocatalytic decomposition processes.

Although the explanation for why radiation-induced blisters form where they do in M9 and graphite-free JA2 was not immediately obvious, it was always clear the blisters align with the direction of extrusion (for stick propellant) or roller-milling (for sheet stock propellant). It is proposed that voids form where they do in transparent samples because of scattering and subsequent absorption of radiation by unplasticized nitrocellulose fibers. The occurrence of bare fibers in NC-based propellants is not at all uncommon in double base propellant. SEM examination of plasma-exposed graphite-free JA2 supports this proposed explanation.

4. CONCLUSION: RELATION OF RESULTS TO TEMPERATURE COMENSATION

Based on experimental investigations and critical analysis of data from the literature, it is proposed that the phenomenon of "temperature compensation", i.e. ability of plasma ignited guns to compensate the performance level of hot and cold propellants, is the result of enhanced gas generation by plasma-exposed propellant, and that enhanced gas generation results in a rapid rise in pressure and the "bootstrapping" of the ignition process. A graphical representation of this phenomenon is given in Figure 3, where the arrow represents how plasma ignition results in enhanced gas generation that gets the system sufficiently pressurized that the propellant bed can ignite and achieve sustained combustion in a fraction of the time required when ignited by conventional igniters.

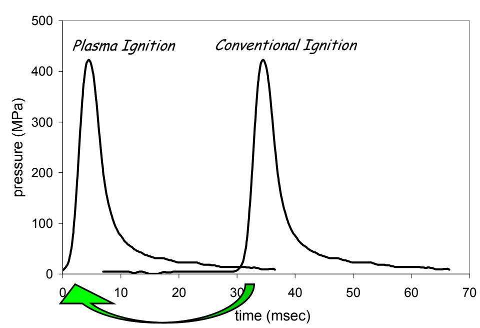

Figure 3: Pressure-time traces for plasma and conventional ignition. Arrow indicates how time required to achieve initial pressure increase is reduced by use of plasma ignition.